# 2015 Summer Course

# on Optical Oceanography and Ocean Color Remote Sensing

## Introduction to Remote Sensing

Curtis Mobley

Delivered at the Darling Marine Center,
University of Maine
July 2015

# This Lecture

- Basic terminology used in ocean color remote sensing
- Forward and inverse models: Remote-sensing is a radiative transfer inverse problem
- Illustrations of the need for atmospheric correction
- Brief comments on terrestrial vs. ocean-color remote sensing

# Data Resolution

The quality of remote sensing data is determined by the spatial, spectral, radiometric and temporal resolutions.

- Spatial resolution: The “ground” size of a pixel, typically ~1 m for airborne to ~1000 meters for satellite systems
- Spectral resolution: The number and width of the different wavelength bands recorded.
- Radiometric resolution: The number of different intensities of radiation the sensor is able to distinguish. Typically ranges from 8 to 14 bits, corresponding to $2^8 = 256$ to $2^{14} = 16,384$ levels or "shades" of color in each band. Useable resolution depends on the instrument noise.
- Temporal resolution: The frequency of flyovers by the sensor. Relevant for time-series studies, or if cloud cover over a given area makes it necessary to repeat the data collection.

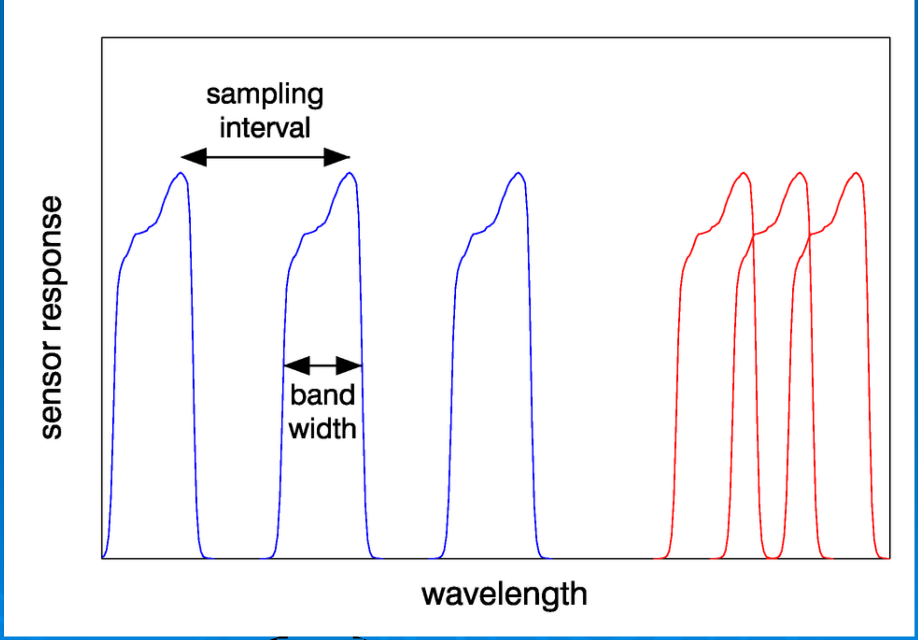
# Spectral Resolution

Monochromatic:
1 very narrow wavelength band, e.g. at a laser wavelength

Panchromatic:
1 very broad wavelength band, usually over the visible range (e.g., a black and white photograph)

Multispectral:
Several (typically 5-10) wavelength bands, typically 10-20 nm wide

Hyperspectral:
30 or more bands with 10 nm or better resolution
Typically have >100 bands with ~5 nm resolution



# Data Processing Levels

- Level 0: Unprocessed instrument data at full resolution (volts, digital counts)

- Level 1a: Unprocessed instrument data at full resolution, but with radiometric and geometric calibration coefficients and georeferencing parameters appended, but not yet applied, to the Level 0 data.

- Level 1b: Level 1a data that have been processed to sensor units (e.g., radiance units) by application of the calibration coefs. Level 0 data are not recoverable from level 1b data. Science starts with Level 1b data.

  Atmospheric correction converts Level 1b TOA radiance to normalized reflectance $[\rho]_N$ at the start of Level 2

- Level 2: $[\rho]_N$ and derived geophysical variables (e.g., chlorophyll concentration, bottom depth) at the same resolution and location as Level 1 data.

- Level 3: Variables mapped onto uniform space-time grids, usually with missing points interpolated, complete regions mosaiced together from multiple orbits, etc.

- Level 4: Model output or results from analyses of lower level data (i.e., variables that were not measured by the instruments but instead are derived from these measurements).

# Modeling

A *model* is a representation of the real world, which tries to retain the essential features of nature while discarding the less important details.

Predictive: Predict something we don't know from something we do know, e.g., predict the radiance from the IOPs and boundary conditions (HydroLight)

vs.

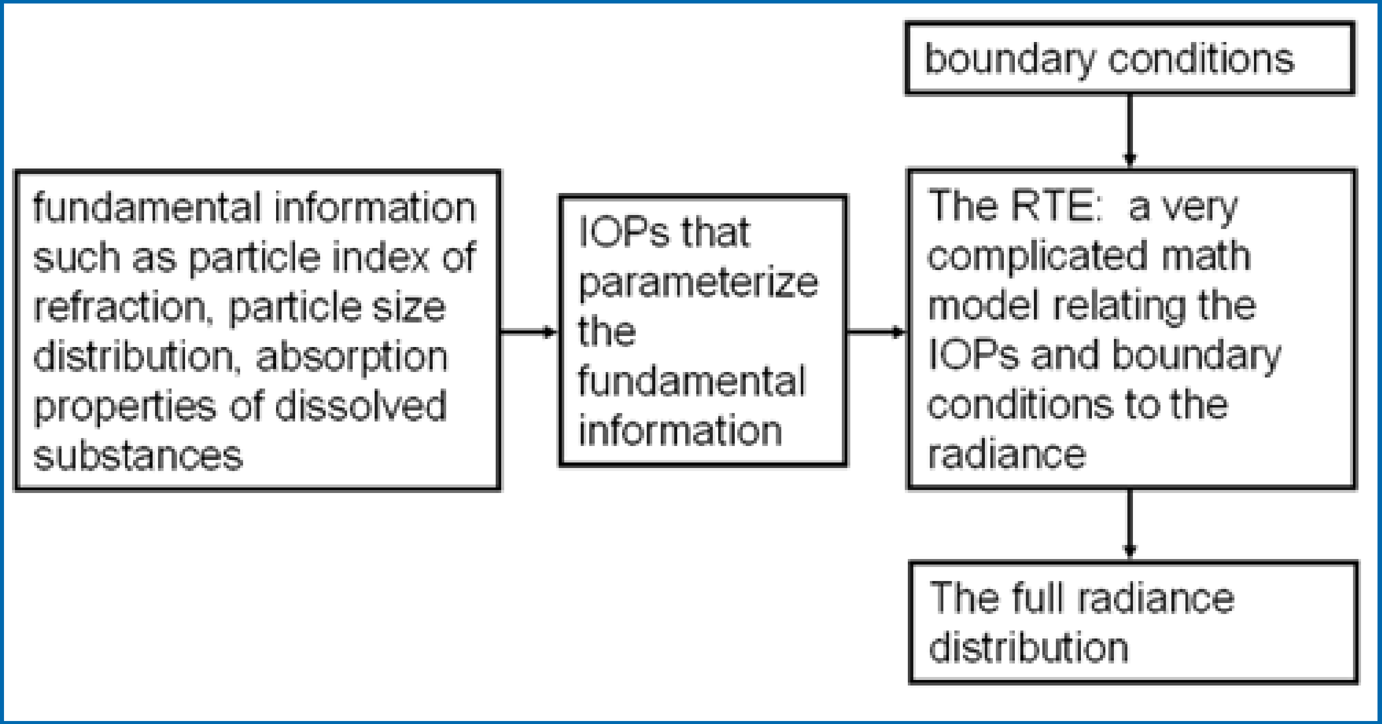
Diagnostic: Analyze or transform known information, e.g., curve fitting to data to show that the data fit a given theory

Direct or Forward: E.g., solve the RTE to compute the radiance given the IOPs

vs.

Inverse: E.g., deduce the IOPs given the radiance

# The Radiative Transfer Forward Problem




This is a solved problem: We know how to solve the RTE. All you need is accurate inputs and computer time.

In one viewpoint, the RTE is a predictive, forward model whose variable input parameters are the IOPs and the boundary conditions, and whose output is the radiance.

# Remote Sensing is an Inverse Problem

Inverse problems may have a unique solution *in principle* (e.g., if you have complete and noise-free data), but *they seldom have a unique solution in practice* (e.g., if you have incomplete or noisy data). For example, there may be more than one set of IOPs that give the same $R_{rs}$ within the error of the $R_{rs}$ measurement.

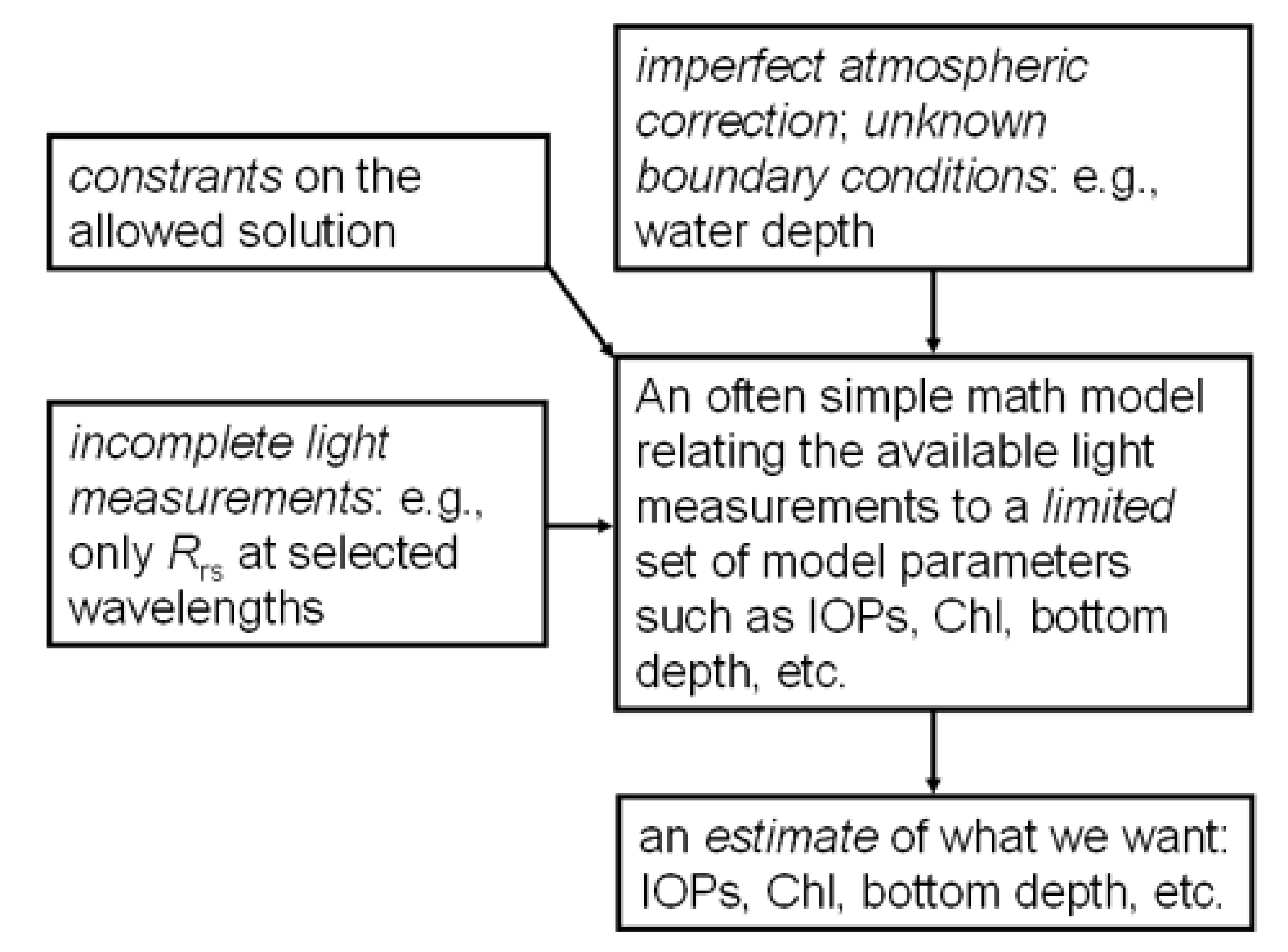
To solve an inverse problem, it is usually necessary to either

(1) add constraints on the solution, to eliminate "wrong" or unphysical mathematical solutions, or

(2) solve for only limited information given the available data (e.g., solve for only $b_b/a$ given $R_{rs}$)

We always have to worry about non-uniqueness when solving inverse problems, including remote sensing.

# The Remote-Sensing Inverse Problem



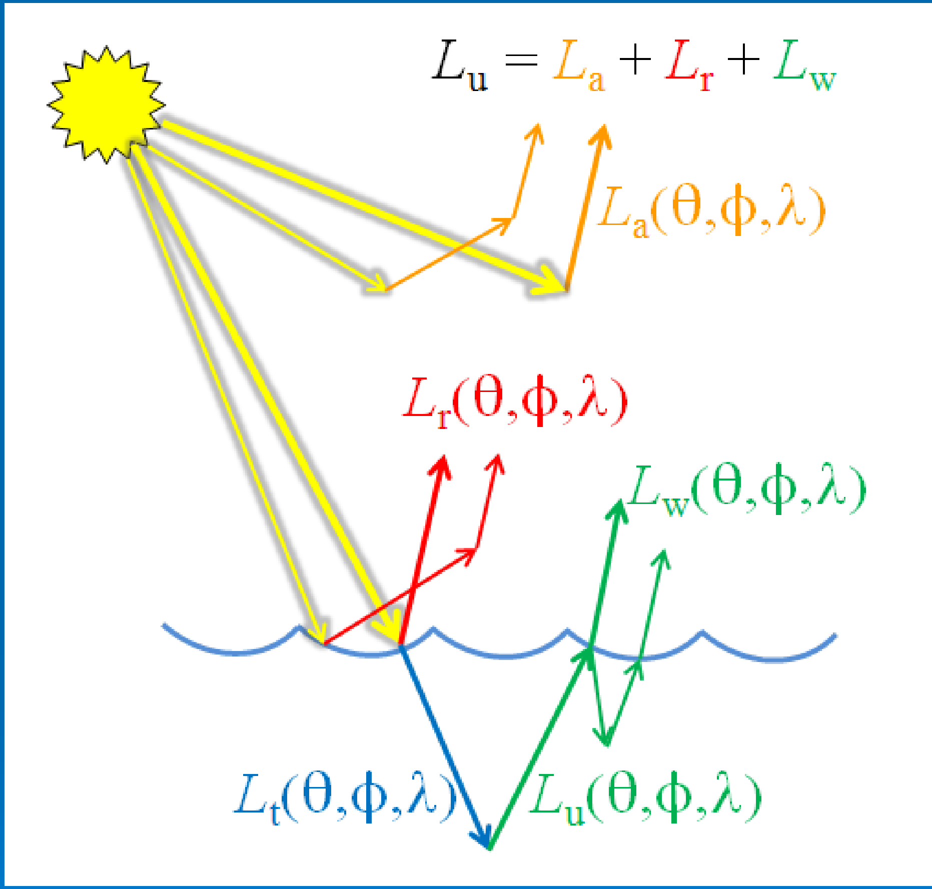

This is NOT a solved problem. There are many models for retrieval of the same thing (based on different simplifications and data sets), and there are uniqueness problems.

# Explicit and Implicit Inverse Problems

*Explicit solutions* are formulas that give the desired IOPs as functions of measured radiometric quantities or AOPs. A simple example is Gershun's law, $a = -(1/E_o)\, d(E_d - E_u)/dz$, when solved for the absorption in terms of the irradiances.

*Implicit solutions* are obtained by *solving a sequence of direct or forward problems*. In crude form, we can imagine having a measured remote-sensing reflectance (or set of underwater radiance or irradiance measurements). We then solve direct problems to predict the reflectance for each of many different sets of IOPs. Each predicted reflectance is compared with the measured value. The IOPs associated with the predicted reflectance that most closely matches the measured reflectance are then taken to be the solution of the inverse problem. Such a plan of attack can be efficient if we have a rational way of changing the IOPs from one direct solution to the next, so that the sequence of direct solutions converges to the measured reflectance or radiance.

# Atmospheric Correction




A sensor measures the total upwelling radiance $L_u$

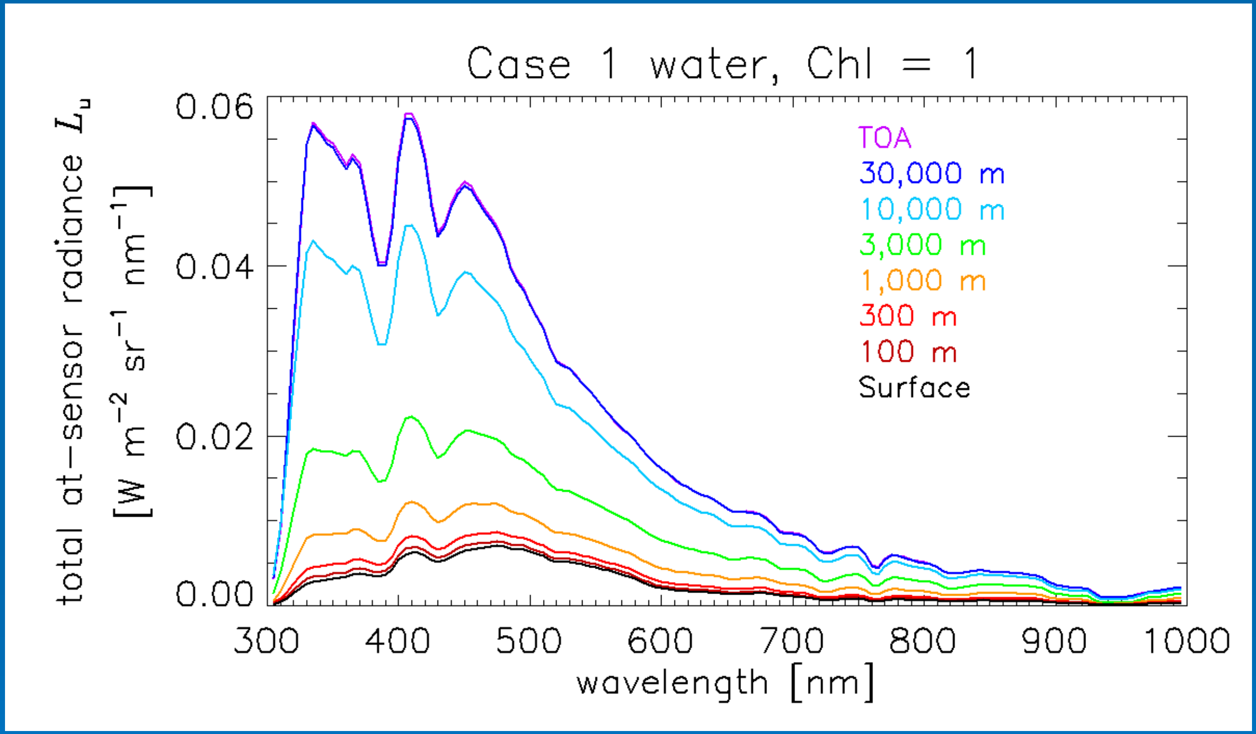
The water-leaving radiance $L_w$ is the part that carries information about the water column

The surface reflectance $L_r$ and atmospheric path radiance $L_a$ are noise (to us), which must be removed from the measured $L_u$

*Atmospheric Correction* is the process of removing unwanted contributions to $L_u$ in order to estimate the desired $L_w$.

# Atmospheric Correction

$L_u$ as a function of sensor altitude, simulated by a coupled HydroLight-MODTRAN code




Atmospheric correction is needed if the sensor is more than ~300 m altitude (less if not clear atmos)

The MODTRAN inputs were

- cloudless mid-latitude summer atmosphere
- marine aerosols
- relative humidity of 76% at sea level
- solar zenith angle of 50 deg
- surface wind speed of 6 m/s
- nadir-viewing sensor

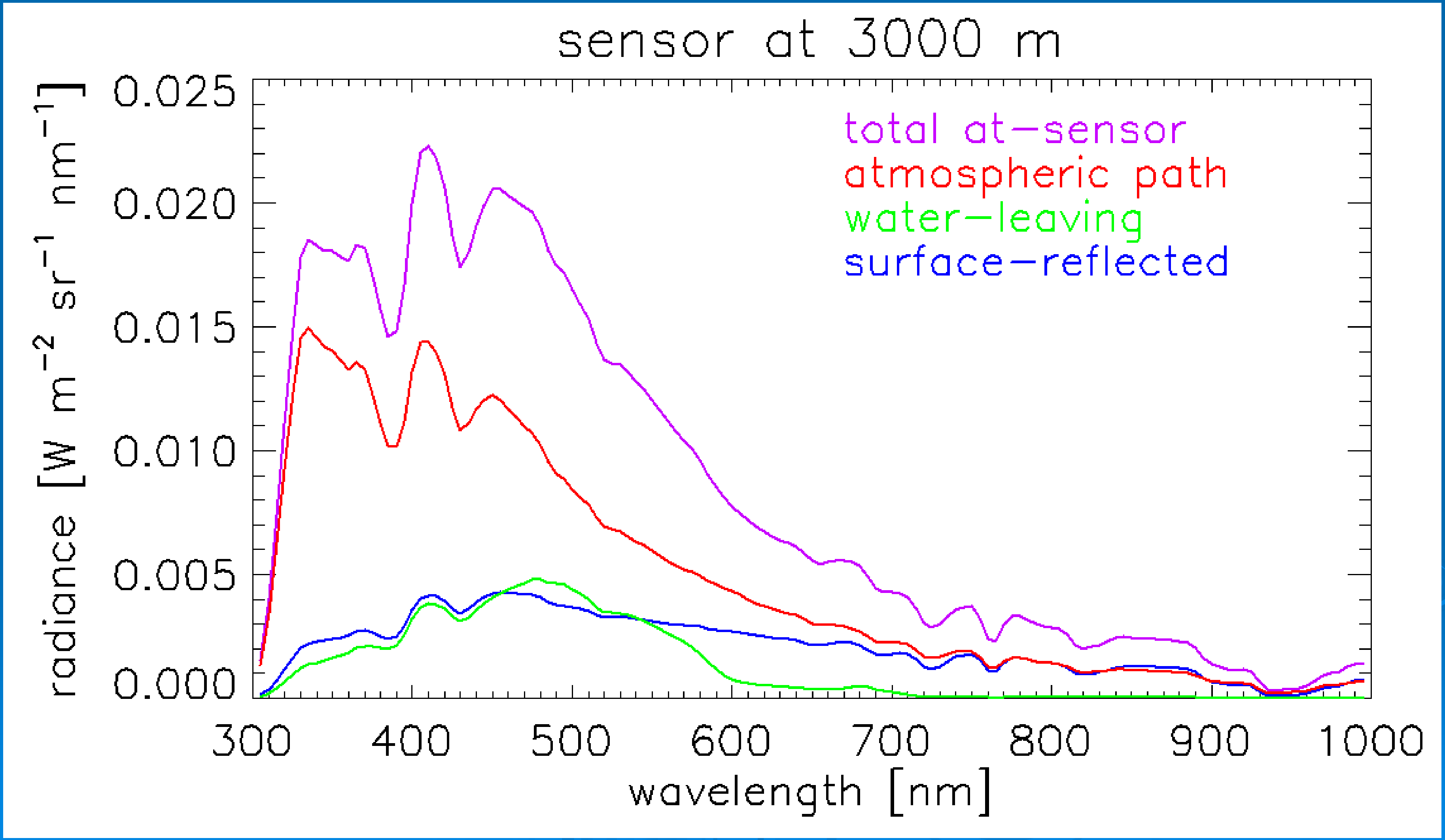
These atmospheric conditions gave excellent remote-sensing conditions with a horizontal visibility of 63 km at sea level.

The HydroLight inputs were for

- homogeneous water
- Case 1 water with a chlorophyll concentration of 1 mg/m$^3$
- infinitely deep water

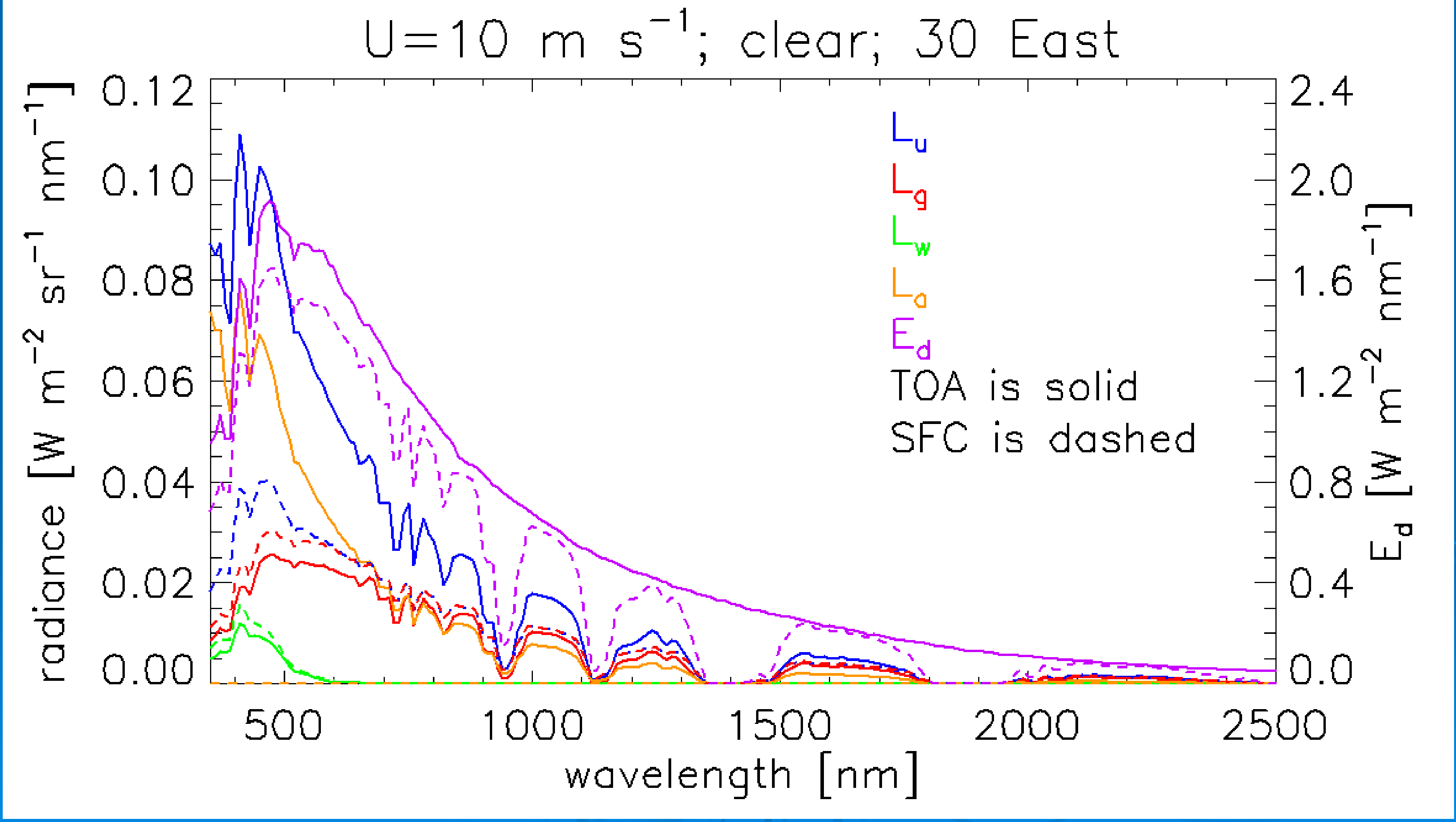
# Atmospheric Correction

Contributions to $L_u$ (3000 m)



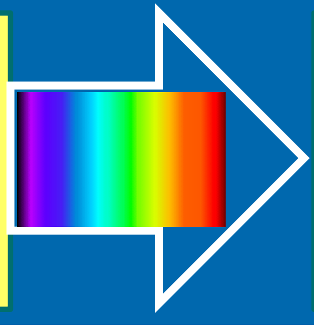
# Atmospheric Correction

## Contributions to $L_u$ (TOA)

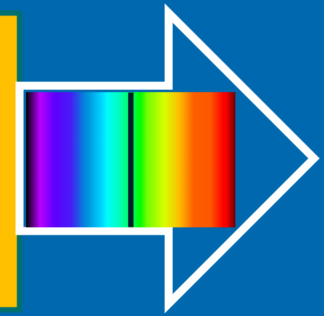


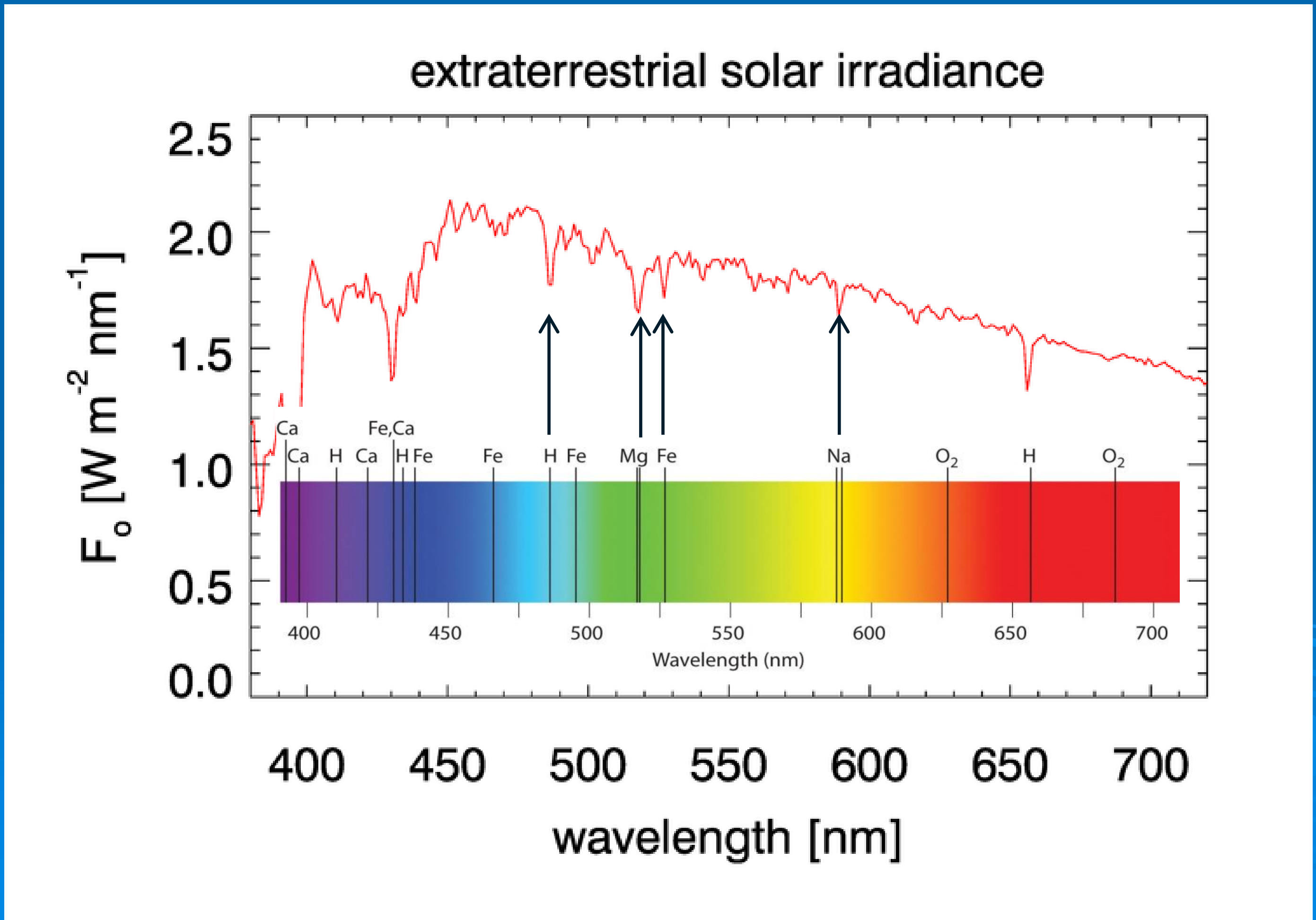
# Fraunhofer Lines in Solar Spectrum

deep, dense, hot region emits a continuous spectrum



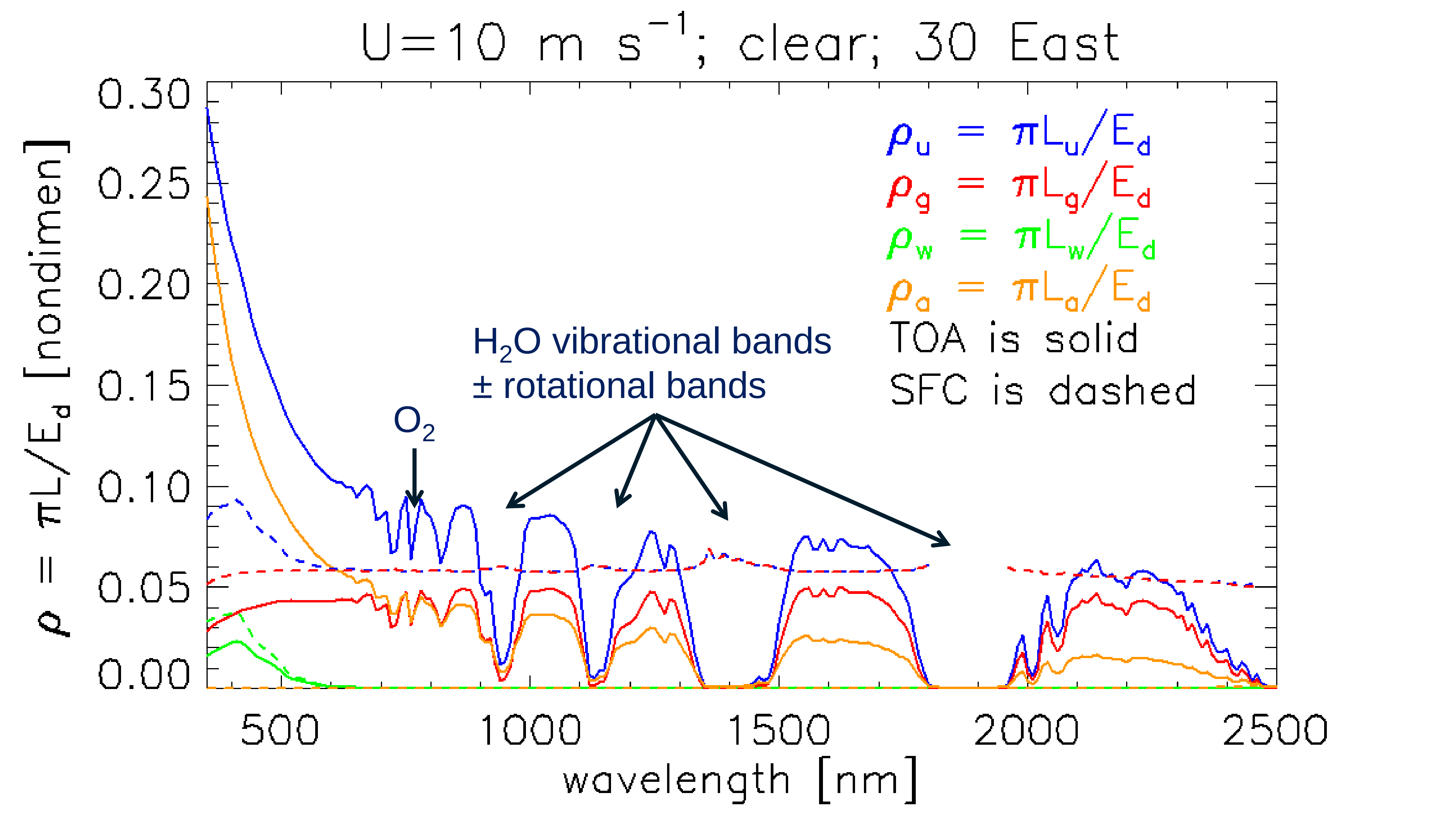
gases in cooler, less dense outer region absorb, re-emit in all directions. Less light in original direction looks darker





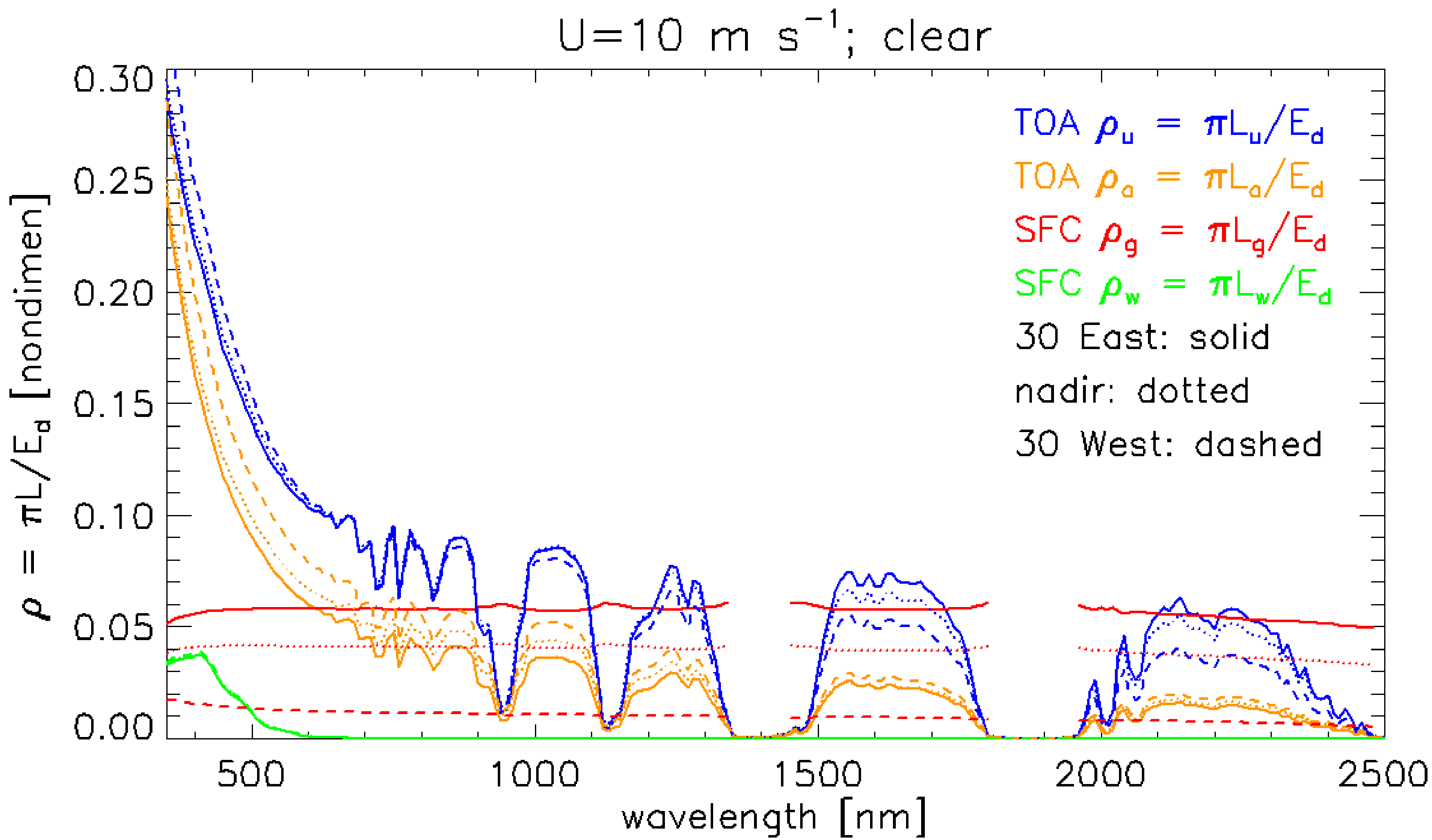
# Atmospheric Correction

Same data plotted as $\rho = \pi L_u / E_d$



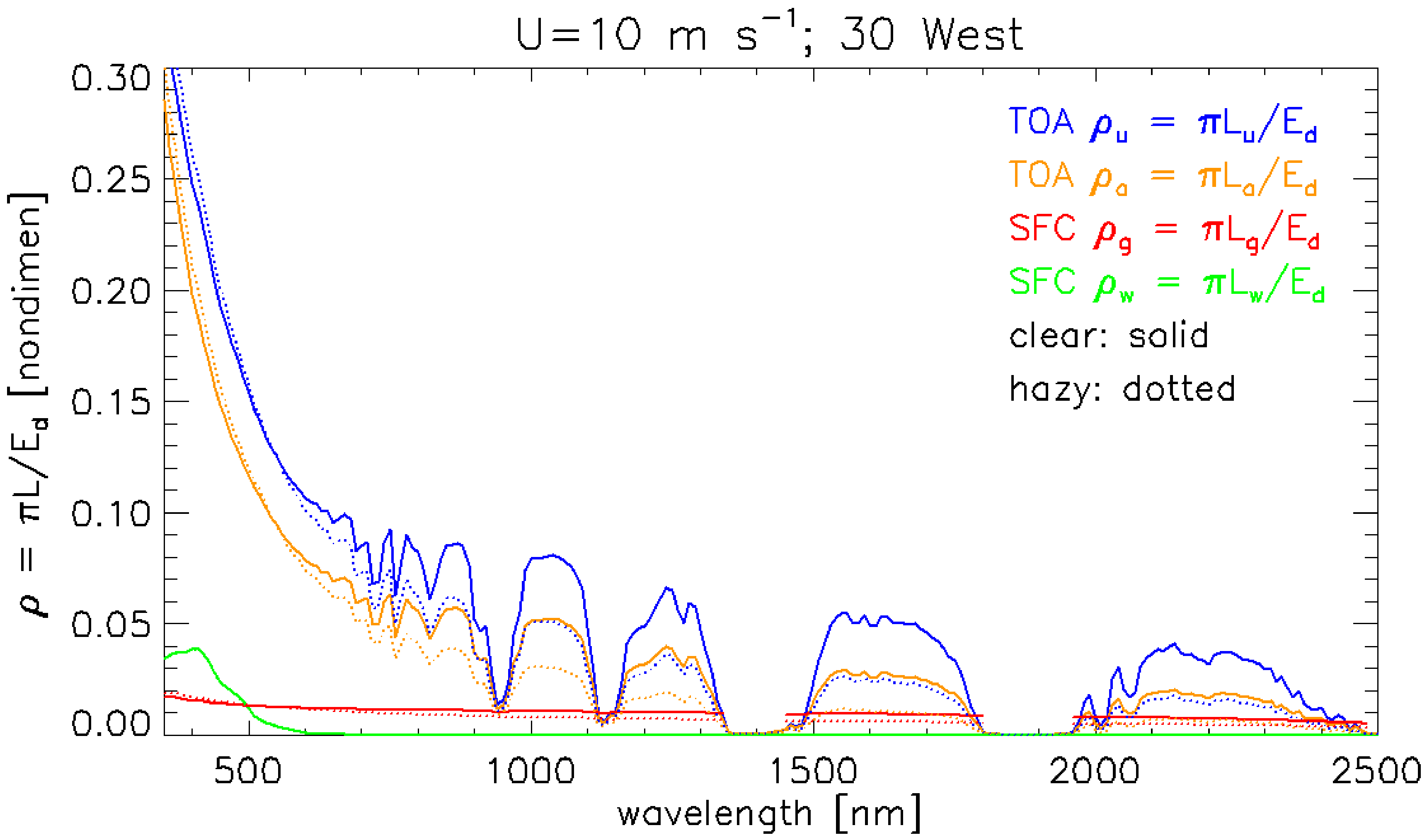
# Atmospheric Correction

## Viewing angle effects



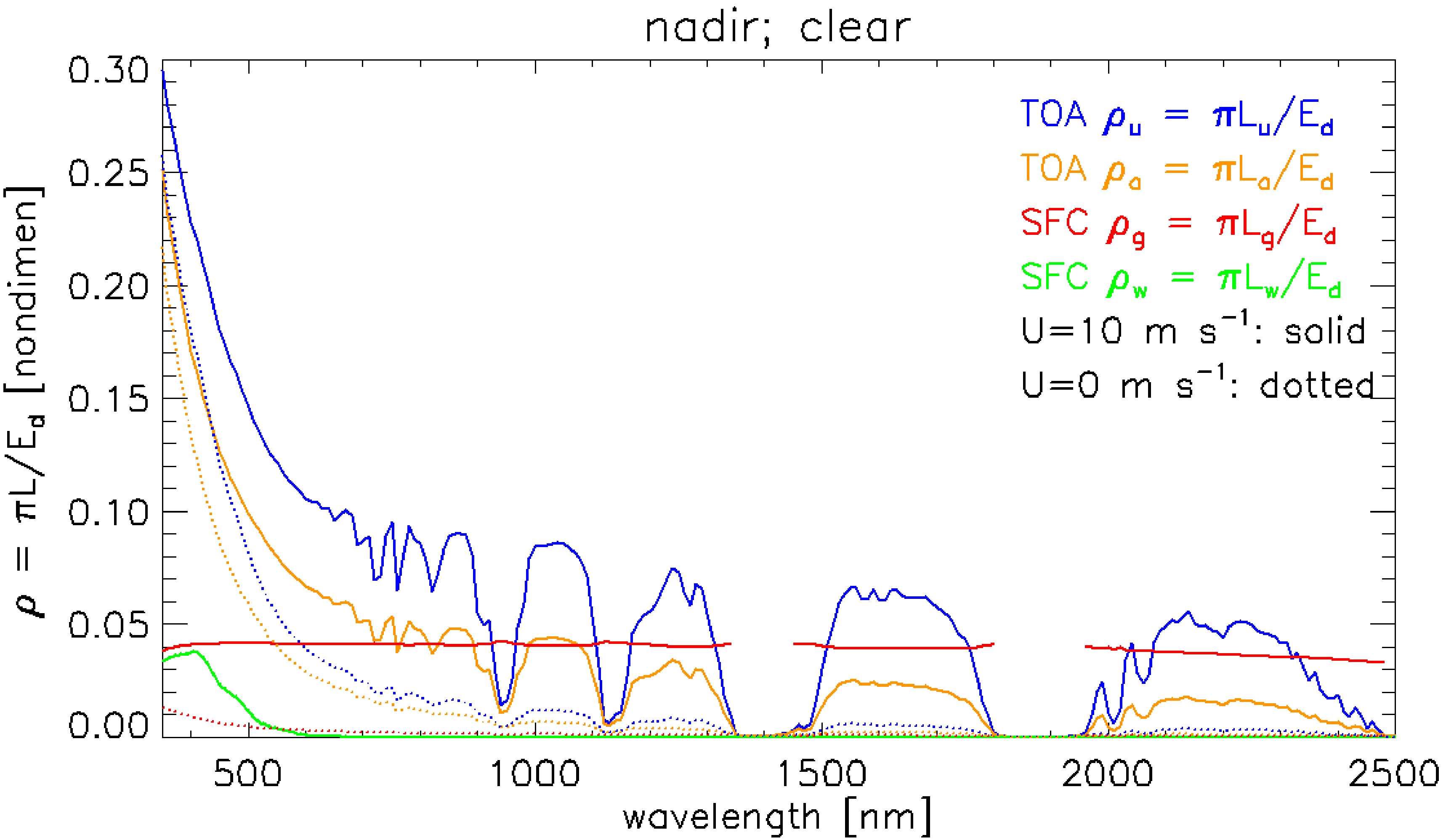
# Atmospheric Correction

## Aerosol effects (clear vs hazy)



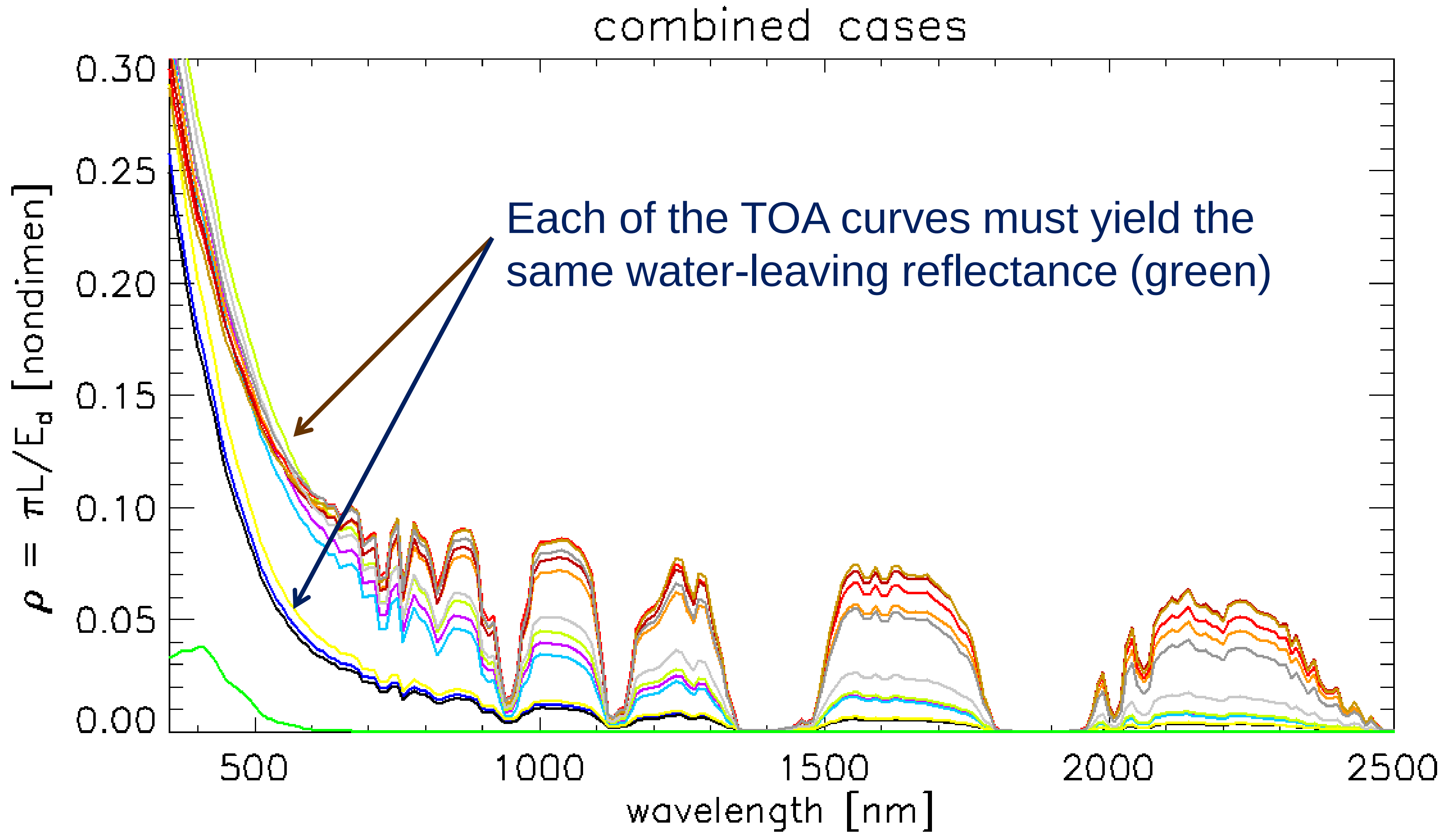
# Atmospheric Correction

## Wind speed effects



# Atmospheric Correction

## Combined effects



# Terrestrial vs Ocean Remote Sensing

Ocean remote sensing is much more difficult than terrestrial remote sensing.

Land is much brighter than water, so the total TOA radiance is much larger over land, and the atmospheric contribution to the total is relatively less, so that atmospheric correction is easier. Sensor signal-to-noise ratio is greater over land.

Terrestrial remote sensing is usually concerned only with mapping the type of surface (thematic mapping), after atmospheric correction.

Ocean remote sensing wants in-water or bottom properties, which are complicated by surface effects (glint), and the water itself when mapping bathymetry or bottom type.

Supervised classification techniques developed for thematic mapping of land types do not work for mapping of bottom types. See www.oceanopticsbook.info/view/remote_sensing/level_2/thematic_mapping

A very clear atmosphere with 100 km visibility. On the West Buttress of Denali, Alaska, at about 5,300 m (~17,000 feet) (summit is 6,194 m = 20,320 feet) Photo by Curt Mobley (temperature = -30 deg C = -22 deg F)